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GEOMORPHIC FORMS AND PROCESSES IN THE HIGHLANDS OF EASTERN VICTORIA

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Abstract

Rock rivers and stepping of valleys in association with boulder cascades on the highlands about the headwaters of the Indi and Buchan R. are described and attributed to Pleistocene periglaciation; a glacial origin for large amphitheatre-like valley heads developed in this region is discounted. Fossil solifluction deposits at Mt Hotham are described. Attention is drawn to dominant lithologic and structural controls in the stepping of upland valleys and slopes formerly thought to be evidence for Pleistocene glaciation or periglaciation.

Introduction

This paper is concerned with the question of glaciation and periglaciation of the Victorian highlands; it is essentially a miscellany, a by-product of structural and stratigraphic investigations, and does not attempt to review the entire question. Its purpose is rather to describe and account for previously unrecorded rock rivers developed on rhyodacites on peaks about The Cobberas and Mt Wombargo at the head of the Indi and Buchan R.; to describe and account for the previously undescribed stepping of valley heads occurring in association with boulder cascades in the same area; to discuss the problem of amphitheatre-like valley heads on The Cobberas and adjacent rhyodacite peaks; to draw attention to the presence of appreciable fossil solifluction deposits and, following on from this, to assess generally the significance of stepping of valleys and slopes as evidence for Pleistocene glaciation or periglaciation.

The reader interested in prior literature on this question in Victoria is referred to the works of Carr and Costin (1955), Costin (1957), and Beavis (1959). Relevant works on the glaciation and periglaciation of adjacent parts of New South Wales are those by Jennings (1956), Browne (1957), Browne and Vallance (1963), and Galloway (1963). The older literature and an appreciation of the differing viewpoints can be garnered from the literature cited in these works. Broader aspects of the ecology, climate, soils, and geology of the upland regions of E. Victoria have been discussed in the High Plains Symposium of the Royal Society of Victoria (1962). The present investigation has not been concerned with the potency of contemporary mechanical processes about and above the timber line. Frost spalling still occurs on the highlands (Pl. 18, fig. 5), and in many localities is contributing to the rapid opening up of cleavage, bedding and joint planes and the prising out of shales and slatey rocks (Pl. 18, fig. 6). Needle ice is important in keeping disturbed upland soils in a state of disaggregation. Snow patch erosion is so restricted in extent and limited to such small areas that, taken alone, it cannot be regarded as a significant contemporary periglacial phenomenon.

The highlands of E. Victoria consist of scattered remnants of formerly more extensive gently undulating to vaguely stepped upland surfaces surrounded by

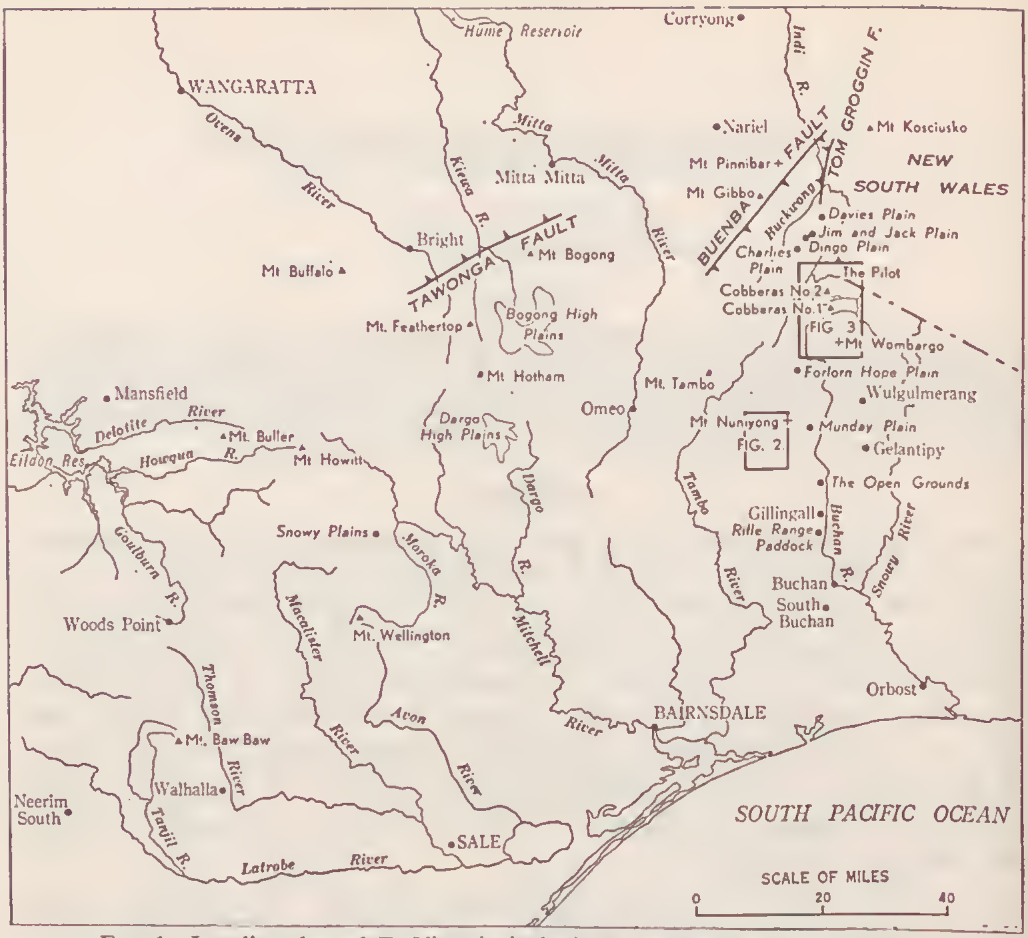

FIG. 1—Locality plan of E. Victoria including localities cited in the text, and location of Fig. 2 and 3.

strongly dissected, steeply sloping country with sharp interfluves and V-shaped valleys. They have developed on a wide variety of sedimentary and igneous formations (Neilson 1962), the most prominent of the upland surfaces bevelling their summits being remnants of formerly widespread Tertiary basalts filling depressions in the old Lower Tertiary surface. There are scarps obviously connected with differential erosion, e.g. Mt Pinnibar, and monadnocks projecting above areas of relatively planar surface, e.g. The Cobberas. There is some complication from Cainozoic faulting and warping connected with the Kosciusko Uplift, though it is only the larger faults such as the Buenba and Tawonga faults, or recent faults such as the Tom Groggin Fault, which attract attention (Fig. 1). The upland surfaces bevel the high parts of E. Victoria more or less regardless of the distribution of the main belts of rocks. Though from afar they may appear to be dismembered parts of a former plain or peneplain or series of peneplains, a closer inspection reveals that the problem of these old surfaces is not so simple because the uplands

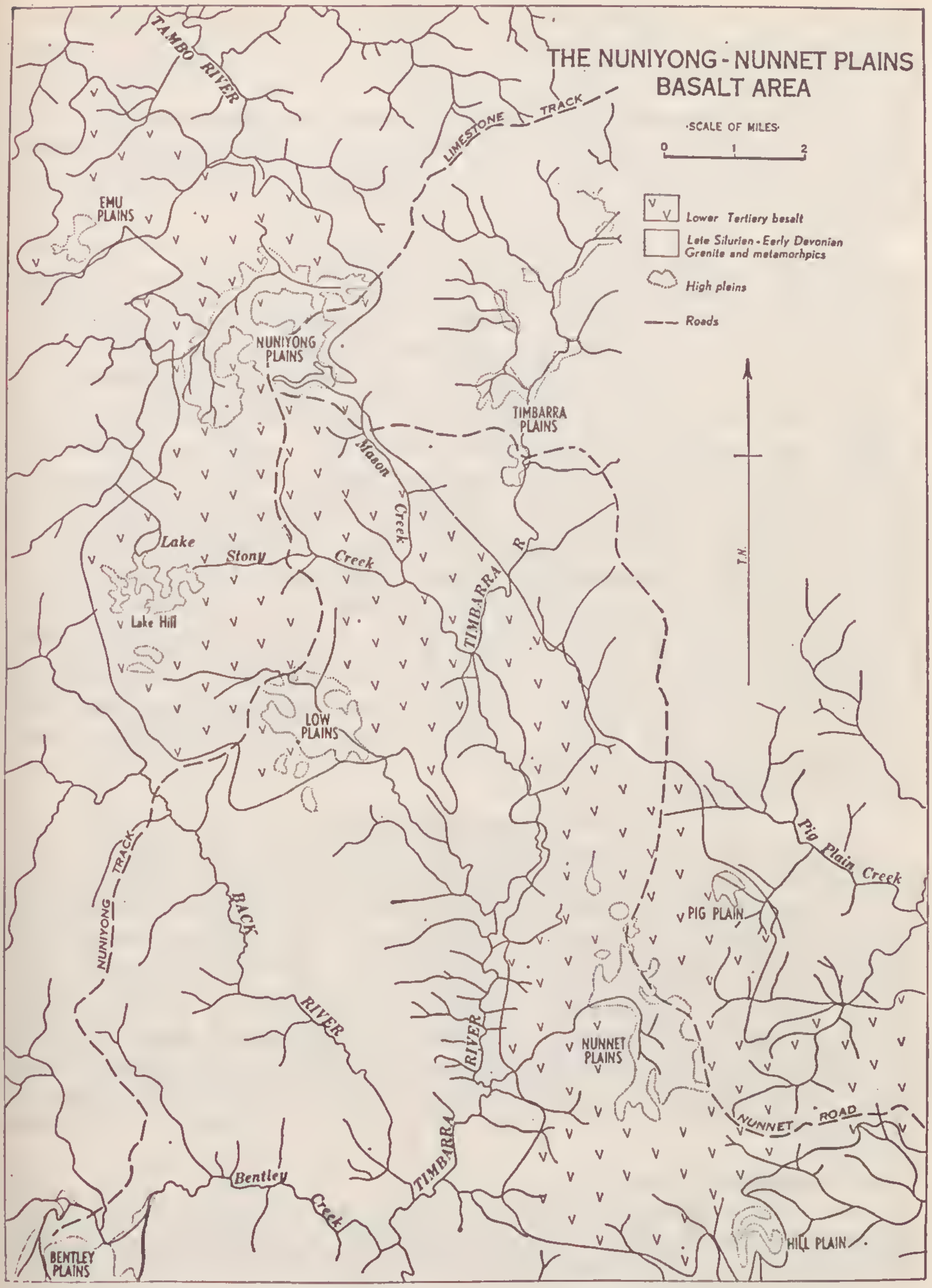

FIG. 2—The Nuniyong-Nunnet plains Lower Tertiary basalt area to show the various localities mentioned in the text (from unpublished geological plan Omeo 1 mile sheet by J. A. Talent, P. E. Bock, K. J. Reed, and R. C. Glenie).

resolve into a series of 'levels' tending to defy correlation over extended distances. There is little or no truly flat surface—much of a given area of upland, e.g. Nuniyong-Nunnet Plains (Fig. 2), will be found to slope more than gently with the upland flats at different levels merging into one another by sloping land with declivities of the order of 400-800 ft per mile. The problem of these old surfaces in the Victorian highlands is a fascinating one awaiting detailed study. Attention is drawn to them here purely as background to the discussion, particularly of the significance of stepping of valleys and slopes to follow later in this paper.

In contrast with the adjacent Kosciusko massif in New South Wales, there are no known moraine-dammed or glacially scoured lakes in the Victorian highlands. Natural bodies of water are rare; the majority of these are shallow stretches of open water an acre or two in extent associated with soligenous bogs, e.g. Moss Bed Lake, Lake Kelly, and the lakelets on Forlorn Hope and Munday's plains. Lake Nigothoruk or Tali Karng near Mt Wellington is unique for the Victorian highlands, being due to a large rockfall of Upper Devonian rhyolites (Howitt 1891; Howitt, Lucas, and Dendy 1891; Thiele 1905). Lake Omeo, in contrast, is due to Quaternary faulting. There are a few examples of natural ponds associated with the Lower Tertiary basalts. The most conspicuous of these is the nameless lake and its satellite on the top of mesa-like Lake Hill between Nuniyong and Low Plains. The lake is shallow, 2'-2'6" in depth, about 390 yds along its longest axis and is situated on a near planar surface with shallow basaltic soils and frequent outcrops of basalt. A meteoritic origin can be discounted by the near planar surface of its immediate surroundings and the absence of an elevated rim; a glacial origin can be discounted by the absence of moraine or other evidence of glaciation in the region. It appears to be a primary depression of the old Lower Tertiary basaltic surface, similar to those at Wulgulmerang and on the Monaro Tableland in S. New South Wales, e.g. Lake Maffra. It recalls some of the lakes associated with the Newer Volcanics of the Western District of Victoria. Trench formations, almost exclusively the gamma-type (McElroy 1952) can be found on many of the natural clearings on the highlands of E. Victoria.

Rock Rivers or Block Streams

Carr and Costin (1955) and Costin (1957) have already mentioned rock rivers in association with the basalts of the Bogong and Dargo High plains. Jennings (1956) has described rock rivers from near the head of the Tumut R. in New South Wales and has invoked periglaciation for their genesis. His description corresponds so closely to the Victorian basaltic examples that these will not be discussed further here beyond mentioning that they are widespread on steep slopes around basalt residuals in the Victorian highlands and may be spectacular, e.g. at Mt Tabletop near Mt Hotham. There appears to be no published record of rock rivers developed from a rock type in Victoria other than basalt. For this reason an account is now given of spectacular rock rivers developed on rhyodacites about The Cobberas and Mt Wombargo, occurring well above the lower limits for development of basaltic rock rivers.

1. Mt Wombargo and Big Hill

Great rivers of rhyodacite boulders are common on the N. and W. slopes of Mt Wombargo (5,400 ft) and the somewhat smaller but morphologically similar Big Hill (5,250 ft), extending down to altitudes of about 3,900 ft (Pl 21; Pl. 19, fig.

1-4, 6). The distribution of these is shown on Cobberas one mile geological map (Talent, Bock, and Glenie 1964). On Mt Wombargo the rock rivers consist at the surface of blocks varying in size from 6 in. to 2 ft with larger blocks up to 8 × 4 × 3 ft, i.e. several tons in weight; on rare occasions blocks of greater size occur. The rock rivers extend for as much as 600 yds downslope and have a maximum unvegetated or poorly vegetated width of 53 yds with greater widths at the junction of tributaries; in general the unvegetated central portion is 12-20 yds in width. In all cases some allowance must be made for a greater lateral extent now masked by soil and vegetation; this cover hampers interpretation for much of the area.

The average slope is of the order of 26° with slopes down to 20°. Flatter slopes of the order of 4½-5° occur at the head of the surveyed rock river (Fig. 4) above the surveyed tract where it starts to dissipate among a series of bluffs of rhyodacite 15-20 ft in height. Flatter slopes occur where rock rivers run out onto flatter ground, e.g. along the NW. side of Mt Wombargo (Pl. 21).

The rock rivers may be distinctly convex in transverse profile, but in general they occupy a slight depression on the hillside. The main body of most of these rock rivers remains unvegetated or with occasional trees growing among the boulders. There may be areas where soil is not far removed from the surface and others where the soil occurs in a pocket in the surface of the rock river. On flatter areas of descent there is an increased tendency to carpeting with soil and vegetation. Each river is associated with a seepage or even an appreciable flow of water issuing from its foot; rarely is there any evidence of surface flow of water on a rock river and where there is it is very localized and in no way alters the impression of all drainage being beneath the boulder accumulation. The rock rivers themselves have the rough morphology of surface drainage, being joined in small measure by tributaries and having a tendency to disintegrate towards their head into a series of feeders; their relationship to surface drainage will be obvious from a glance at Pl. 21.

A closer inspection reveals that the surfaces of the boulders are fretted to a uniform degree from top to bottom of the rock rivers; the quartz phenocrysts now project above the surfaces of the boulders. The undisturbed growth of trees occurring often in midstream and the apparent lateral extension of the same material into completely vegetated areas on either side reinforces this picture of complete immobility under present climatic conditions. It seems they have been at a standstill for a long time, in view of the appreciable advance of soil and vegetation. One may argue that the centre of such a rock river has had its fines removed by the streamlet associated with it. Surface examination and shallow excavation, however, indicates there is very little fine material in the range ½-3 in. in these accumulations. This seems to indicate that there was no great comminution of the joint blocks once they were freed and that the remarkable proportion of open space is some sort of reflection of the original condition of the mass; this can be verified only by deep excavation. Excavation of the related terraced accumulations (see below) supports considerable primary open space.

The very great thickness of these rocks and the great amount of open space is incompatible with generation in situ. The size and morphology of the boulders argues against derivation from pre-glacial weathering mantles. The most significant facts are that the morphology resembles a stream, running water occurs beneath each rock river and they originate in many cases at a series of low bluffs, indicating that the blocks were derived from the bluffs where, presumably, they were wedged out by vigorous frost action. The massive rhyodacite, impervious except along well spaced joint planes, was eminently suitable as a source of large blocks. They were most probably moved downslope from the bluffs by frost heave, becoming gradually incorporated in a rock 'glacier' with its interstices filled with ice from water from the subjacent spring. In their lack of interstitial filling these rock rivers are similar to the rock glaciers described by S. R. Capps (1910) from Alaska where, too, the interstital filling, if present at all, consists only of ice. The 26° slope of the Wombargo and Big Hill rock rivers is rather higher than the 9-18° slope of the Alaska rock glaciers. Unlike the Alaskan rock glaciers, they do not seem to have been the dying stages of a glaciation but rather the climax of periglaciation reached at this locality. Had they been connected with the dying stage of glaciation there should be a few cirques and moraines in the area.

When active, these rock rivers were comparable in many respects with forms from N. Canada, described by J. B. Tyrrell (1910), in which a mass of ice fills the interstices of a talus, the ice being from the freezing of waters from a subjacent spring; the resultant 'chrystocrene' has a movement intermediate between a creeping talus and a rock glacier.

2. Cobberas No. 1

The Middle Peak on Cobberas No. 1 (Pl. 18, fig. 3, 4) rises above large joint blocks stretching out downslope into the amphitheatre head of Towanga Ck. But the blocks are almost all discoloured, weatherbeaten, mottled by lichens and intergrown with vegetation if not in part buried beneath soil cover. In spite of the strong columnar jointing of Middle Peak there is little evidence of recent fall out around the E. face of the bluff (Pl. 18, fig. 3) and no evidence of injury to trees. The overall impression is of a condition undisturbed for a long time with more leisurely weathering in situ. Here and there down the slope in front (E.) of Middle Peak there is the impression of a rock river, the whole slope being significantly around 27°, comparable to the rock rivers on Mt Wombargo, but the cover of vegetation and soil leaves some uncertainty at first inspection. It is my impression there is an intermittently buried rock river descending into the amphitheatre from Middle Peak. It differs from the examples at Mt Wombargo in having a larger bluff of more spectacularly jointed rhyodacite as source of the blocks.

The most impressive rock rivers in the Cobberas No. 1 amphitheatre descend from the Cleft Peak right down to Towanga Ck and are there well exposed along the sides of the creek (Pl. 19, fig. 4). Their definite river-like orientation downslope, the lack of filling of interstices, the lack of clays and indeed their virtual lack of boulders under 2 in., as well as the dominance of boulders 6 in. or more in size, show their identity in all essential respects with the rock rivers at Mt Wombargo. They, therefore, do not have the morphology of moraines, but again are regarded as formed by chrystocrenes. The rock rivers have continued onto the flatter slopes of the amphitheatre, presumably under the head of rock and ice behind them. They tend, therefore, to merge with the deposits that are associated with stepping of the lower parts of the amphitheatre (see below).

Stepping of Valleys in association with Boulder Cascades

The head of Moscow Ck between the Cleft Peak and Moscow Peak is a deep but comparatively broad valley head with a broad saddle separating it from the head of Bullies Ck (Fig. 3). The terraces within it are of varying shapes (Pl. 23),

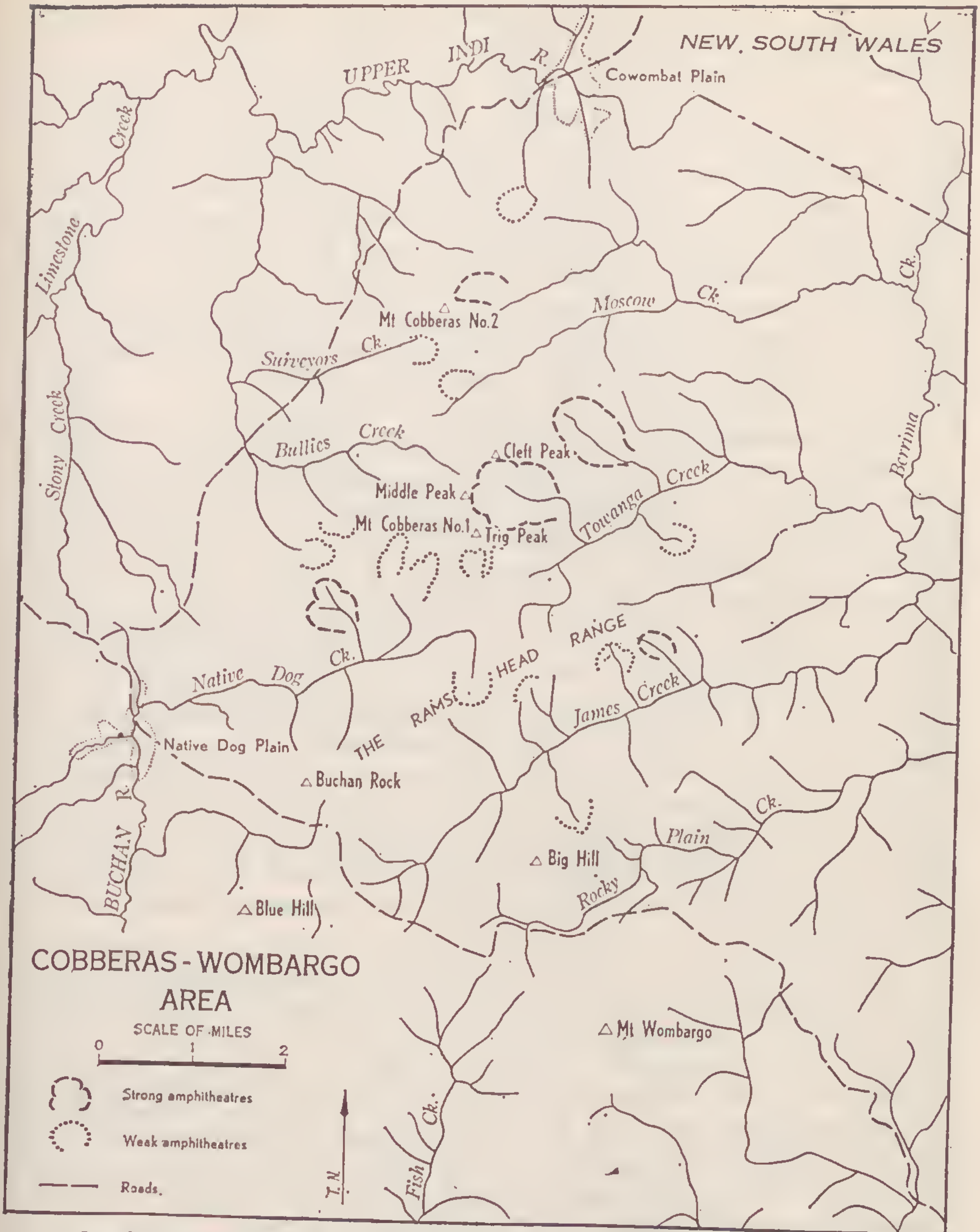

FIG. 3—Locality plan of Cobberas-Wombargo area showing location of strong and weak amphitheatres. Rock rivers in this area are shown on geological plan Cobberas 1 mile sheet (Talent, Glenie, and Bock 1964) and in part on Pl. 23.

occurring as a series related to the principal springs and rivulets. They have gently undulating to flat surfaces sloping at declivities around 1 in 10, but as gentle as 1 in 23, for 50-120 yds, followed by an abrupt steepening to a slope of 1 in 2·5 or 3 (cf. Fig. 4) on each rampart. At some point on this rampart the stream will be found to descend a vertical distance of 7-25 ft through and over a heterogeneous mass of tumbled, well weathered boulders with shrubs and small trees growing among them. The rampart surfaces away from the watercourses are noticeably more rocky than the adjacent terrace surfaces, though they too may be almost completely covered by soil, with only occasional boulders appearing among the cover of snow grass, shrubs, and patches of sphagnum moss with its associated flora. The foot of the rampart or the back of the next terrace tends to be occupied by a boggy area with sphagnum and running water from springs. Running water may cover a comparatively broad sheet of the terrace surface, be restricted to defined and sometimes incised channels, or may flow or seep between the boulders beneath the surface of the terrace. Similar terracing of a tributary of Native Dog Ck is figured (Pl. 22, fig. 1).

The amphitheatre-like head of Towanga Ck between the peaks of Cobberas No. 1 (described above in the discussion of the Cobberas amphitheatres) is 1½ miles across from ridge to ridge at its widest. Except for cliffs high on its slopes and on a peak at the mouth of the amphitheatre, the topography down in the amphitheatre and on its slopes is subdued but complex; the drainage through and over its surface is intricate. The surface cover of the amphitheatre is complex, including rock fall, talus and rock rivers. Terraces similar to those in Moscow Ck occur on small watercourses on either side of the main drainage, but the best terracing occurs in the vicinity of the main stream, or more accurately, along the principal floor of drainage, for water seeps and flows in intricate fashion over a wide area in the centre of the amphitheatre. The terraces in the centre of the amphitheatre (Fig. 4) differ from those in Moscow Ck by their comparative isolation from the amphitheatre walls—they come and go across the principal directions of drainage. Otherwise they are very similar, with a benched portion of boggy to tussocky ground with patches of heath, snow grass and sphagnum, and irregular patches of water among the vegetation and tending to be separated from one another by ramparts of jumbled blocks averaging a foot in diameter, but with large ones up to an observed $6 \times 6 \times 4$ ft. In all cases noted, water was issuing from the foot of the rampart. The boulders or blocks are strongly weathered on their exposed surface; many are mottled with lichens.

A notable exception to the general pattern is a low crescent-shaped terrace about 16 yds long (across the slope), and 14 yds in maximum width in the downslope direction (Pl. 19, fig. 5). It is located about the middle of the amphitheatre at the foot of a normal larger terrace with a rampart composed of a jumble of lichen-mottled rhyodacite boulders; otherwise it is surrounded by bog. It contrasts with other terraces in being raised very little above the surrounding bog, and in bearing no soil on its surface among the boulders. It contrasts with the rampart behind it by its lack of surface vegetation, except for a few shrubs along its downslope boundary with the bog, and in the lack of lichen growth on its boulders. A casual inspection suggests relative youth compared with other terraces associated with boulder cascades in the Cobberas area.

It is composed at the surface of boulders 8 in. to 1 ft in diameter with some up to 2 ft across. Excavation in March 1963 showed that similar boulders with associated smaller boulders occur continuously down to the level of the water and

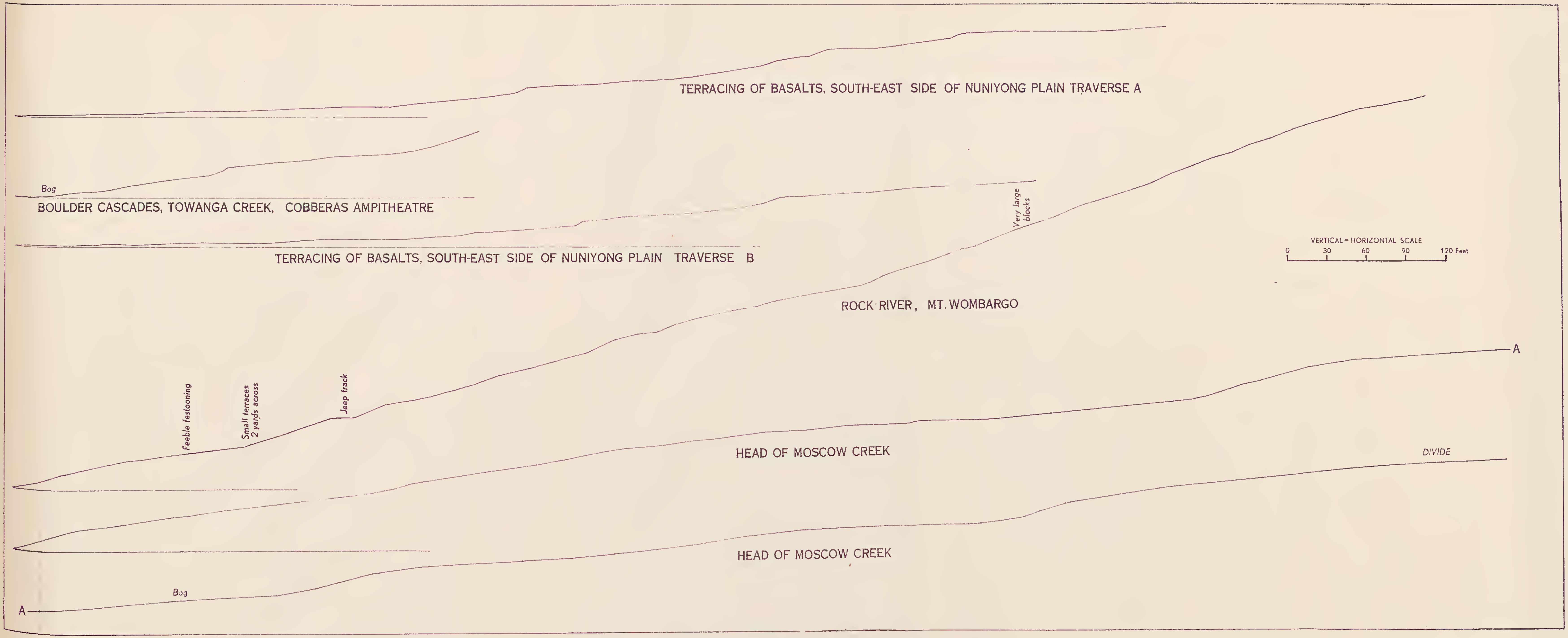

FIG. 4—Abney level profiles of terracing of basalts on the SE. side of Nuniyong Plain (cf. Pl. 17, fig. 1 and 2), typical of the Lower Tertiary basalt residuals of E. Victoria; a rock river on the NW. side of Mt. Wombargo (cf. Pl. 20, fig. 1-3, 6); stepping with boulder cascades on Towanga Ck near the centre of the Cobberas No. 1 amphitheatre, the bare terrace, Pl. 20, fig. 5, being beside the bog at the start of the traverse; a traverse up the head of Moscow Ck to the Great Divide through the terraces with boulder cascades (cf. Pl. 23 where these are emphasized by snow)—the terraces are more impressive in the field than they appear on the traverse.

mud 2 ft below the surface and for at least another foot below that. When the surface boulders are examined closely it is seen that, in spite of the absence of lichens, their surfaces are well fretted leaving the quartz phenocrysts protruding considerably above the surface. The quartz phenocrysts protrude less in boulders beneath the surface; boulders beneath the water table are smooth. The degree of fretting of such resistant rock indicates a considerable antiquity for the surface of the accumulation, with no significant disturbance of the accumulation since the fretting commenced. The absence of vegetation from most of this terrace, therefore, can have no temporal significance. The absence of lichens is not completely understood. There is a strong flow of water beneath the surface of the accumulation. It may be that water flows over the surface for a sufficient period during the year to prevent lichen growth, much as in the case of boulders in the beds of intermittent streams. Such a flushing process for part of the year may explain the lack of soil on the surface of the accumulation. The absence of various small grades from the accumulation indicates the original accumulation was probably essentially free from these grades. It must, therefore, have had a lot of vacant space or have been bimodal with boulders and blocks in a fine matrix.

Evidence for comparative antiquity of the boulder rampart terraces is indicated by the fretting of particularly resistant rhyodacite boulders on their exposed surfaces compared with boulders beneath the surface, the maturity of soils in the better drained portions of terraces, and the near complete cover of vegetation, including trees growing on the ramparts. The fretting of only the outer surfaces of boulders on the ramparts shows these have not been disturbed for a long period. In other words, the configuration of the terraces was achieved sometime in the past and is not connected with contemporary downslope movement of waste.

The contemporary flow of the streams in the valley heads is powerless to move the large blocks over and around which they flow in descending the ramparts of each terrace. The ramparts may include blocks of the order of 1 or 2 tons in weight. I cannot conceive of any stream so near its head ever having sufficient flow of water to move blocks of this size down slopes of the order of 2 or 3° and leave them dumped in such a regular fashion.

It may be argued that these are lag deposits connected with spring sapping at the foot of each terrace, perhaps more vigorous in the past. But then some of this spring sapping should be occurring at the base of bedrock (or more or less bedrock), and not consistently with boulder cascades except for the highest terrace in any sequence. The restriction of these terraces to the heads of the highest valleys in E. Victoria and their absence from morphologically similar valley heads in identical rocks at slightly lower altitudes shows this could not be the fundamental cause. A simple interpretation as glacial moraine would ignore the occurrence of these terraces with boulder ramparts at the head of small valleys, in such a position that there could not have been sufficient head of snow to make a hypothetical glacier move there. The absence of intermediate grades of rock debris from the accumulations is likewise against interpretation as moraine.

The regularity of the terraces and their lack of relationship to cliffs show they cannot be due simply to rock fall followed by accumulation behind the barrier. On the other hand, their intimate relationship with running water at the present day indicates there was almost certainly some connection with water in their genesis. Solifluction and frost heaving were considered an adequate cause of similar block cascades in Wisconsin by H. T. U. Smith (1949). Certainly the freezing of water in the interstices giving an outward thrust would explain the movement of the large boulders a ton or more in weight. The significance of solifluction cannot be estimated for there is no certainty these terraces contained an appreciable amount of soil at the time they were generated; excavation did not clarify this point. Solifluction or no, the size of the blocks in these boulder cascades is so similar to that of the rock rivers in the same area that I am led to conclude they are different facets of an essentially similar process, the one occurring on steep slopes with freezing of waters from a subjacent spring in the interstices of the accumulation, the other occurring on gentler slopes with serial generation of terraces corresponding to a series of springs, with the same process of filling of interstices with ice giving an outward thrust in each case. In the case of the Cobberas No. 1 amphitheatre it seems clear that the generation of many of the boulder cascade terraces has taken place with materials supplied by rock rivers. Elsewhere the two phenomena tend to be separate, but wherever rock rivers emerge onto comparatively gentle slopes, as for example along the NW. flank of Mt Wombargo, they are frequently stepped. A more detailed study of these terraces should take into account possible relationships to the Russian 'goletz' and the altiplanation terraces of North America.

Mr Eric Woodford has drawn my attention to single terraces with boulder ramparts developed on the E. side of small rhyodacite peaks near the heads of Goodwin and the Lower Limestone Ck NW. of Wulgulmerang. Each of them is associated with bogginess or weak spring activity, and in each case there is a noticeable amphitheatre effect, but all of them have the appearance of long inactivity. They are clearly single terrace examples of the same phenomena just described and more elaborately developed on the peaks about The Cobberas and Mt Wombargo.

The Cobberas Amphitheatres

Cirque-like valley heads are widely distributed in the Victorian highlands associated with a variety of lithologic and structural controls. They may be found in association with slumping of clayey sediments, with solution effects on carbonate rocks, and around the margins of Tertiary basalts where there has been spring sapping. Some of the valley heads developed on rhyodacites about The Cobberas (Fig. 3) have pronounced amphitheatre shapes and on such a scale that they warrant more than cursory mention. One of them has already been described as a glacial cirque (Costin 1957), and indeed others could be described as cirques were it not for the absence of moraine, the absence or near absence of clay in such accumulations as occur within them (see above under rock rivers and boulder cascades) and, in the case of weaker forms, the occurrence of similar forms at lower altitudes on rhyodacites elsewhere in the Snowy River Volcanics belt. The largest of these amphitheatres formed by Cobberas No. 1 about the head of Towanga Ck is not illustrated because the flights of timber-assessing photos used in Pl. 22 did not give stereo cover for that area. The coverage for Cobberas 1 mile sheet at a scale of approx. 1: 31,300 (cf. Pl. 21), while adequate for field work, was not good enough over Cobberas No. 1 for reproduction; some description is therefore necessary. Contours of this area are to be found on the standard topographic sheet Cobberas (Victorian Lands Department) and the 1 mile to 1 inch geological plan of Cobberas 1 mile sheet (Talent et al. 1964).

Cobberas No. 1 is sickle-shaped in plan, opening ESE. and exceeding 6000 ft at the Cleft Peak in the N. and at the Trig Peak located at the junction of 'handle and blade'. It is of pronounced amphitheatre shape, 1½ miles across at its widest, with slopes of the order of 20°, steepening to an average of 27° down rock rivers, to 50° on rocky outcrops and with a few cliffs, mainly around the crest, of 70° to nearly 90°. The floor flattens to a minimum gradient of only a few degrees along Towanga Ck and the boulder cascades in the centre of the valley, then descends 850 ft in a horizontal distance of half a mile, the first 400 ft being by a series of waterfalls. It requires special consideration because it has been described (Costin 1957) as having the 'form of a large shallow cirque at the base of which are large accumulations of boulders, in the form of moraine, now largely vegetated' in addition to 'smaller accumulations of smaller stones . . . largely unvegetated' farther upslope, and 'tiny cirque-like hollows on the eastern side'.

Except for recent talus, the various boulder accumulations of the Cobberas No. 1 amphitheatre are described above. Though I regard the boulder cascades and the rock rivers to be Pleistocene in age, I could not conceive that any of these accumulations were moraine, nor could I find evidence of two periods of development characterized by size of boulders and degree of vegetation. One barer deposit in the middle of the amphitheatre (Pl. 19, fig. 5), perhaps one of the 'smaller accumulations of smaller stones' referred to by A. B. Costin, has been described above and its relative bareness ascribed to causes other than lack of antiquity. The boulder cascades do run across the valley as one might expect of moraines, but the rock rivers themselves are aligned down the sides of the amphitheatre from the bluffs, analogous to the paths taken by streams of water. There is no difficulty discriminating between these older deposits and recent talus or rock fall, though the volume of talus is small considering the peaks about The Cobberas are some of the most rugged in E. Victoria (cf. Pl. 18, fig. 1-4; Pl. 23).

The main problem for consideration is why the Cobberas No. 1 amphitheatre (abnormally large for a cirque), the amphitheatres on either side of it, and the one on the side of Cobberas No. 2 are hanging with respect to Towanga, Native Dog, and Moscow Ck and why they have a similar morphology. Close analogues of these amphitheatres do not occur on adjacent peaks such as Blue Hill, Big Hill, or Mt Wombargo and are not found on other high peaks in the region: Mt Pinnibar, Mt Gibbo, Mt Nuniyong. This suggests peculiar local circumstances, particularly as the most cirque-like of these amphitheatres (Pl. 22), draining into Native Dog Ck, is lower than the others (not quite 5000 ft above sea level) and is not backed by a considerable catchment for snow.

A bending profile down the Cobberas No. 1 amphitheatre could be projected to join the head of Native Dog Ck without a notable change in gradient. It may be, therefore, a dismembered portion of that creek captured by the rejuvenated Towanga Ck. This would account for the knick point and waterfalls, but would not account for the amphitheatre joining Towanga Ck farther to the NE., nor the amphitheatre on Native Dog Ck 1⅜ miles SW. of Cobberas No. 1 Trig Peak having a rather similar morphology. It seems to me significant that both Towanga and Native Dog Ck are located on the same NE.-SW. lineament and that creeks to the N. can be grouped in pairs on parallel lineaments: Bullies Ck and the right branch of Moscow Ck; Surveyor Ck and the left branch of Moscow Ck. Streams to the S.—James and Rocky Plains Ck and the heads of Fish Ck have all picked up the same direction. I believe these to be old fault zones, but this has not been verified. However that may be, they are lines of easier excavation which have been picked out by the main drainage so that streams running across the adjacent rhyodacites have difficulty competing with the speed of downcutting of the main drainage; they are accordingly left in a hanging position.

If this explains the hanging relationship of the Cobberas amphitheatres to the main drainage, it still does not explain their shape. Could they be glacial? The possibility of some glacial action cannot be denied, but there is no strong supporting evidence other than the shape (gentle compared with the overdeepened cirques at Mt Kosciusko) and an orientation roughly towards the SE. On the other hand, I have found no indubitable polish, striae, plucking, or moraines associated with these amphitheatres. What happened to the immense volume of rock carved out in producing these forms? Why has it been completely removed from the amphitheatres and the valleys farther downstream? It seems to me these amphitheatres are much older than the period of refrigeration responsible for the periglacial deposits now draping their sides and floors. Because of the absence of proved moraine or other indubitable evidence of glaciation I hesitate to refer the amphitheatres to an earlier period of refrigeration. Rather I regard them as due to differential erosion of very hard rocks over a long period of time in which zones of shattering, closer jointing, and subtle differences in lithology have been picked out.

Solifluction Deposits

The apparent rarity of thick solifluction deposits in the Victorian highlands may be due to lack of investigation for there are two notable deposits exposed in road cuttings on the Alpine Highway at Mt Hotham which have not been recorded.

One deposit is located at the Diamentina Drift in a NE.-facing valley head of the Diamentina R. around the 6000 ft level about 25 chains W. along the Alpine Way from the junction with the road to the Red Robin Mine. It is a jumble of soil and rock fragments formerly exceeding 20 ft in maximum thickness and being about 70 yds across at its widest point. Part of it above the Alpine Highway has been excavated for road construction material; the surface has since been smoothed out. Part of it lies below the road and was formerly overlain by a moss bog; this has been destroyed and erosion has cut into the distal end of the accumulation. It is the site of a fairly persistent snow drift.

A similar deposit occurs at the Davenport Drift on the Alpine Way about 1 mile SE. of the junction with the road to the Red Robin Mine. It is a similar deposit to that at the Diamentina Drift, facing ENE., except that it is on a steeper slope and has been developed from basaltic soils and basalt boulders. The boulders have been broken down to lumps 1-4 in. across with occasional larger lumps, mixed with a lot of soil to an unknown depth (several feet). The size of the basalt boulders provides a contrast with the larger basalt boulders littering the surrounding slopes. Frost action is indicated by the angularity of the fragments and degrees of comminution of the boulders.

Cutting of the Alpine Way has caused some renewed downslope movement of both deposits, though removal of much of the Diamentina Drift deposit has arrested this activity. In both cases there is annual deep freezing of these water-saturated accumulations (K. Terry pers. com.). Both deposits are essentially fossil, but in view of this it is uncertain to what extent they are Pleistocene.

Stepping of Upland Valleys and Slopes

The stepping of valleys and slopes may reflect a dominant structural control such as bedding or major jointing; it is most conspicuous when associated with sharp contrasts in lithology. Further comment is necessary because stepping, in association with other geomorphic forms, has been adduced as evidence for Pleistocene glaciation of the Baw Baw and Buffalo granitic massifs, the basaltic Dargo High Plains, and the Snowy Plains-Mt Wellington area (Costin 1957).

1. Stepping on the Baw Baw and Buffalo Granitic Massifs

It is well known that the rectangular drainage pattern and the stepping of valleys on granitic rocks is controlled by major joint patterns and by faults and dykes of igneous rocks and are developed under a variety of climatic conditions. The following discussion, therefore, will not probe this fundamental principle, but will consider only the two areas of Victoria where valley stepping on granitic rocks has been attributed to glacial or periglacial activity.

The geology and scenery of the Buffalo Plateau has been mapped, described, and copiously illustrated by E. J. Dunn (1908). It is sufficient, therefore, for the present discussion to reiterate that the landscape there is dominated by a rectangular drainage pattern among rocky residual peaks (tors). Rock buns, known in Victoria as tors, are widespread; there is a general absence of rocky material from the narrow, treeless, poorly drained, peaty flats along the principal watercourses except in the vicinity of stepping or near the margins of the plateau. A. B. Costin (1957, p. 234), in discussing this area, refers briefly to the valley of the creek leading to Dickson's Falls being of this general type except that 'a short distance upstream from where the tourist road to the Horn crosses the creek . . . the valley narrows suddenly and the creek cascades down through about 100 yards of boulders'. This, along with the 'bouldery condition of the rest of the plateau' (presumably the rock bun dominated landscape) and the 'virtual absence of large boulders from the broad expanse of valley' was regarded as consistent with the existence of a cirque glacier or even a small valley glacier.

An explanation of the relative absence of boulders and rock buns from the peaty valley floors must take into account the acid conditions prevailing in these tracts, the augmented weathering of felspar in granitic rocks in this environment, the accumulation of soils on these flatter areas, and inorganic and organic sedimentation in a swampy milieu. The rock buns are demonstrably generated in situ from large joint blocks by weathering along joints coupled with exfoliation of surfaces exposed to the atmosphere (discussed in Dunn's memoir). Where there are road cuttings exposing rock and rotten granite, the joint pattern of the granite will be found to continue uninterrupted into the weathered rock with patches of less weathered or more or less unweathered granite blocks retaining their structural relationships to one another (Pl. 17, fig. 4) and in harmony with the jointing of the granitic bedrock. Such assemblages have not been moved, though with deflation of the surface by wind, water, and hillside creep they would become part of the loose rock on the surface. No cuttings reveal unusual accumulations of granite boulders or boulders requiring movement by ice to explain their occurrence.

At the top of the previously mentioned cascade there are 27 yds of unbroken outcrop of granite bedrock (Pl. 17, fig. 3); massive granite outcrops in the bed of the cascade for 7 out of every 10 yds of its descent. The intervening cover is thin, with other granite outcrops, some of which could well be continuous with the bedrock. There is only one set of blocks rising above the general surface—it is located right at the top of the cascade. It retains the joint directions of the granitic bedrock showing it has developed in situ (Pl. 17, fig. 5); it has been neither dumped nor moved. The stepping of the valley (Pl. 17, fig. 6) at this locality accordingly is not connected with glacial moraine. It is related to the major jointing of the granite, though I have not gone into the details of its generation.

Similar considerations are involved in the geomorphology of the Baw Baw Plateau. There are the same broadly concave valleys, peaty flats, tors, rock buns, and strong control of drainage by the rectangular pattern of major joints in the granite (Baragwanath 1925, p. 25, 19, Pl. 15-18, map). The stepping of Tullicoutty Glen (cf. Pl. 20, fig. 2) and the heads of the Tanjil R. (Pl. 20, fig. 1) and Whitelaw Ck (Costin 1957) is considered to be explicable by the normal processes of erosion without need to invoke glaciation or periglaciation. The major stepping at the head of Tullicoutty Glen noted by A. B. Costin coincides with a major NE.-SW. joint or shear which can be traced for approximately 6 miles across the Baw Baw Plateau. The change downstream from a broadly concave to a V-shaped valley coincides with a convergence of two major NW.-SE. joints controlling as well the direction of the two heads to the glen. A search of this valley did not prove the existence of moraine. The head of the West Tanjil R. and its tributaries shows a remarkable set of steps and rectangular control of drainage by the pattern of major joints (Pl. 20, fig. 1), with constriction of valleys at each major step. If this were essentially due to glaciation it would be anomalous for the glaciers would have to have taken right angle bends.

2. Stepping on Basaltic High Plains

The normal law of retreat of lava-capped summits is as a series of steps separated by noticeably steeper slopes due to the layered nature of lava accumulations and to interbedded sediments, soil horizons or volcanic ash. Such stepping has not previously been emphasized in Victoria, but its occurrence on Tertiary basalts at all altitudes down to sea level shows this is not necessarily due to glacial or periglacial activity.

Stepping has already been recorded for the basalts of the Bogong High Plains (Carr and Costin 1955). These remnants are known to consist of many flows with interbedded tuffs and sediments (Beavis 1962). Mapping of the Nuniyong-Nunnet Plains area and boring of the Dargo High Plains has shown these bodies of basalt to be complex and that there is a connection between terracing and layering.

There have been several accounts of the geology of the Dargo High Plains with reference to the mining of the deep leads beneath the basalt, culminating in a detailed geological map on a scale of 40 chains to the inch (Hunter 1895). In 1900 and 1901, an E.-W. line of 5 bores was drilled there at Gow's Plains by the Mines Department of Victoria; 4 of these reached bedrock and the fifth terminated before reaching the deep lead beneath the basalt sequence. The published logs of 4 of these bores (Hunter 1902) indicate up to 8 discrete flows, some separated by beds of lignite, clay, and sand, and others separated by zones of vesicular basalt or decomposed basalt. It is possible to recognize some of these differing flows in the hand specimen on the basis of their texture and weathering characters and to demonstrate that some at least of the steps about Gow's Plains correspond to changes in lithology of the basalts. Correlation between stepping and layering of the basalts seems reasonably proved; this is reinforced by the restriction of stepping to the basaltic area and its absence from the adjacent Ordovician sediments at higher and lower levels than the basalts.

There is remarkable stepping of the previously unmapped large area of Lower Tertiary basalts extending from Emu Plains through the Nuniyong and Low Plains to Nunnet Plains (Fig. 2 for localities; Fig. 4 for profiles). There is a difference in height of more than 700 ft between the highest surface of this basalt body on Lake Hill, seemingly a slightly modified relic of the Lower Tertiary surface after extrusion of the basalts, and the lowest level of basalt in the Timbarra Gorge 3 miles to the SW.; an appreciable relief of the Lower Tertiary surface is indicated for this area. There is major stepping of the area with Lake Hill standing as a mesa above the surrounding plains with a series of gross terraces in most directions as one descends from it, with smaller terraces between and within the various plains to the limits of the basalt (Pl. 17, fig. 1, 2); there is often a well defined terrace between the basalt and the exhumed granite surface surrounding it. Some of the terracing is demonstrably connected with variation between basalt flows observable in the hand specimen (vesicularity, crystallinity, macroscopic olivine content and weathering characters).

Though terracing of the basaltic high plains can be shown in part at least to be due to layering of the basalts and interbedding of sediments and tuffs, the steepening of slope at each terrace would have provided a favourable situation for frost prising and, in steeper situations, the generation of block streams under periglacial conditions. As was discussed earlier and has been recognized by other workers (Carr & Costin 1955, Costin 1957) this is what occurred around the basaltic high plains of Victoria during the Pleistocene.

Concluding Remarks

Above about 5000 ft in the Victorian highlands the familiar processes of erosion at lower altitudes are supplemented by an increase in frost heave and frost spalling indicating an approach to an alpine regimen. Our knowledge of these processes in Victoria is rudimentary and needs to be expanded as a preliminary to disentangling what is contemporary and what should be attributed to a past alpine or periglacial regimen. It is not surprising that fossil periglacial features are not particularly conspicuous or may even be absent over considerable areas where they formerly existed, for substantial changes in micro-geomorphology will have resulted from overall erosion and other geomorphological processes since the Pleistocene. Unprotected and weakly expressed glacial or periglacial forms would have been readily erased. Some grosser products of periglaciation such as large rock rivers, stepping of valleys with boulder cascades and solifluction deposits have survived as fossil features testifying to past refrigeration. The significance of lithology and structure should be evaluated before a glacial, periglacial, or other origin is ascribed to a given geomorphic form. Ignoring these factors, or, conversely, overemphasizing them, may lead to distorted or erroneous views of their genesis.

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